Nature Conservation 46: 1–16 (2022)
doi: 10.3897/natureconservation.46.71109
https://natureconservation.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

# Comparison of methods to estimate the size of Indian pangolin (*Manis crassicaudata*) scale seizures using species-specific conversion parameters

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Academic editor: Mark Auliya | Received 5 July 2021 | Accepted 19 December 2021 | Published 10 January 2022

*http://zoobank.org/B09CB3AA-BB22-4802-9218-16E86701D665*

Citation: Algewatta HR, Perera P (2022) Comparison of methods to estimate the size of Indian pangolin (*Manis crassicaudata*) scale seizures using species-specific conversion parameters. Nature Conservation 46: 1–16. https://doi.org/10.3897/natureconservation.46.71109

## Abstract

The absence of robust species-specific methods to estimate the number of animals in seizures of pangolin scales is a major barrier to effective law enforcement. Therefore, studies focused on developing methods to establish accurate conversion parameters are a priority. This study proposes improved methods to estimate the number of pangolins in the illegal trade to inform law-enforcing authorities. Based on the observations of 25 specimens, Indian pangolins were on average found to possess 511 scales. Three morph-types of scales were identified: broad rhombic (n=411), elongated kite shape (n=69), and folded scales (n=31). The mean dry weight of the three-scale morph-types was 7.5 g, 4.9 g, and 6.2 g. Based on the average frequency and mean dry weight of each scale morph type, the species-specific dry weight of scales for Indian pangolins was 3.6 kg. Accordingly, we propose new and improved methods based on scale morph-type frequencies and species-specific dry weight of scales to estimate the number of Indian pangolins from quantities of scales. Their accuracy was compared with current methods, and the improved methods were found to be more accurate.

## Keywords

CITES, conversion parameters, illegal wildlife trade, pangolins, scale seizures, Sri Lanka

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## Introduction

Illegal wildlife trade (**IWT**) has become one of the most significant contemporary global conservation issues that threatens biodiversity (Biggs et al. 2017; Harfoot et al. 2018). This multi-billion-dollar industry has rapidly escalated in recent decades and has taken center stage in the global conservation policy agenda ('t Sas-Rolfes et al. 2019). The international IWT has been largely driven by poaching African elephants and rhinoceroses, while the pressure on endangered taxa such as tigers and pangolins has increased over recent decades (Rosen and Smith 2010; Biggs et al. 2017).

Pangolins (Pholidota: Manidae) are the most trafficked wild mammals, being heavily exploited across their range in Asia and Africa (Shepherd 2009; Challender et al. 2014a; Heinrich et al. 2016; Ingram et al. 2018). IWT of pangolins is primarily driven by the demand in Asian countries, especially China and Vietnam (Pantel and Chin 2009; Challender 2011; Challender et al. 2014b; Nijman et al. 2016). Pangolin are used in traditional Chinese medicine (largely scales), and pangolin meat is considered a delicacy in many Asian and African countries (Challender et al. 2015; Shairp et al. 2016). The increased exploitation has led to a drastic decline of pangolin populations in Asia (Wu et al. 2004; Challender 2011; Challender et al. 2015). Simultaneously, a perceptible increase in the trafficking of African pangolins, almost exclusively scales, to Asian markets has occurred (Challender and Waterman 2017).

Indian pangolin has been in IWT since the early 2000s, where scales are predominantly sourced in India and Pakistan being trafficked to China along routes through Myanmar and Nepal (Challender and Waterman 2017). Indian pangolin at present is under considerable hunting pressure due to local consumption and rising demand for its scales and meat in East Asian markets (Baillie et al. 2015; Mahmood et al. 2019; Perera and Karawita 2020). The virtual extirpation of *M. pentadactyla* and *M. javanica* in East Asia is believed to be the primary driver of demand for *M. crassicaudata* in the present international IWT (Challender and MacMillan 2014; Mohapatra et al. 2015; Mahmood et al. 2020). The Indian pangolin populations in India and Pakistan have been over-exploited for international trade, and the growing demand and awareness of the lucrative markets for pangolin scales have expanded the source markets to Sri Lanka and Nepal (Challender and Waterman 2017; Perera et al. 2017; Mahmood et al. 2019). For instance, recent studies suggest local niche markets for pangolin meat and scales with a possibly growing international IWT of *M. crassicaudata* scales from Sri Lanka to South India (Perera et al. 2017; Perera and Karawita 2020).

Pangolins are usually trafficked as whole animals for their meat, possibly descaled and disemboweled (Sopyan 2008), and quantifying the number of individuals when whole is simple as they can be directly counted (Challender et al. 2015). However, estimating the number of pangolins being trafficked is more challenging when only scales are involved. Removed scales are dried and typically packed regardless of size or species and traded internationally (Sopyan 2008; Nijman et al. 2016). With a few exceptions, such as black-bellied and white-bellied pangolins, it is difficult to identify the pangolin species involved by visually inspecting scales. However, there is also a lack of capacity/

knowledge among law enforcement personnel to correctly identify the species and their derivatives in illegal trade (Challender and Waterman 2017).

The current method of estimating the number of pangolins, i.e., Whole Organism Equivalents (WOEs), in the illegal trade of scales is weight-based and involves dividing the weight of a given seizure or trade volume by the weight of scales from a specific species (Challender et al. 2015; Challender and Waterman 2017). Robust estimates of the weight of scales only exist for the Chinese and Sunda pangolins (see Zhou et al. 2012). Wet weight (i.e., the weight associated with the moisture content) is more variable than the dry weight of scales. The rate of desiccation varies due to various environmental factors, including temperature and humidity. As such, dry-weight-based methods are more robust in estimating the number of animals from quantities of scales though it may not perform well in the case of Indian pangolin (Zhou et al. 2012).

According to recent studies, there is intra-specific variation in the total number of scales of Indian pangolins, ranging from 440 to 530 (Ullmann et al. 2019; Algewatta et al. 2021; Perera et al. 2021), though these disparities are likely due to different scale counting protocols adopted in various studies (Perera et al. 2020). It is further estimated that the scales account for about 30–35% of the total body weight of Indian pangolin (Mohapatra et al. 2015). Morphologically unique scale types can be observed in Indian pangolins (Perera et al. 2020; Algewatta et al. 2021). The scales differ in terms of the presence of grooves, size, and angle of the scales (Fig. 1). Such detailed morphological characteristics have been described for Indian pangolin (*Manis crassicaudata*) by Algewatta et al. (2021).

Indian pangolin is the only pangolin species recorded in Sri Lanka (Mahmood et al. 2019; Perera and Karawita 2020; Algewatta et al. 2021). There are no records to suggest that Sri Lanka is used as a transit point in the IWT of pangolin scales (Perera et al. 2017; Perera and Karawita 2020). Hence, the seizures of pangolin scales in Sri Lanka contain scales of Indian pangolins sourced from the country. In the Sri Lankan context, neither weight-based nor species-specific scale frequency methods have been used in estimating the WOEs. Hence, studies focused on developing accurate conversion parameters are essential, especially in law enforcement applications. This study establishes more accurate conversion parameters to determine the WOE for Indian pangolin scale seizures with detailed scale morphology and frequency observations.

## Methodology

### Specimen selection

In this study, data on scale frequencies and morphology were gathered from live specimens, fresh carcasses, museum specimens (dry and wet preserved specimens and mounted specimens), and confiscated scale consignments of *M. crassicaudata* by the Sri Lanka Customs. Museum specimens were obtained from National history Museums, Colombo, Sri Lanka (n=4), and the Department Wildlife Conservation museums at

Giritale, Yala, and Galway's Land National Park, Sri Lanka (n=8). Data of wet preserved specimens were gathered from the specimens available at the Department of Basic Veterinary Science of the Faculty of Veterinary Science, the University of Peradeniya, National Zoological Gardens Pinnawala, Postgraduate Institute of Archeology of the University of Kelaniya, Sri Lanka (n=4). Scale counts and measurements of dead/fresh carcasses were obtained from specimens at Wildlife Rescue Center, Kilinochchi (n=2). Seven live specimens from rescue operations were also observed. Accordingly, a total of 25 specimens were observed (seven females and 18 male specimens). The examined specimens further included four juveniles, nine sub-adults, and 12 adult Indian pangolins. In addition, confiscated Indian pangolin scales obtained from Sri Lanka Customs were used for this study.

## Scale counts and measurements

Scale counts were performed manually and using photographs, following the protocols and guidelines described in Perera et al. (2020). Each specimen's dorsal, lateral, and ventral surfaces were photographed using a Canon EOS 70D Digital Single Lens Reflex (DSLR) camera (18–55 mm) to ensure all the scales were captured in the photographs for counting. The images were analyzed using Adobe Photoshop CC 2015 (Adobe World Headquarters, San Jose, California, US) and ImageJ™ (Research Services Branch, National Institute of Mental Health, Bethesda, Maryland, USA) software to perform scale counts. In cases of missing scales due to fall-off, but if it could be determined with confidence that a scale was once present (when there is an evident scale bed), it was considered as a scale (Ullmann et al. 2019). Manual counting was also performed simultaneously to increase the accuracy and for verification.

## Estimating the size of Indian pangolin scale seizures

Given a confiscated mass of pangolin scales, approximating the number of pangolins killed to extract the mass of scales was the study objective. For this purpose, confiscated scale samples by the Biodiversity, Cultural, and National Heritage Protection (**BCNP**) Division of the Sri Lanka Customs were used. Initially, background information of confiscated sample such as initial weight, date and place of the seizure, methods used to estimate the number of pangolins, and legal actions taken against the suspects were acquired. Established methods in literature were used for the approximation process with modifications where necessary (see Estimating the size of Indian pangolin scale seizures A, B, C, D).

### A. Weight-based method (Challender et al. 2015; Challender and Waterman 2017; Zhou et al. 2012)

The weight-based method involves recording the bulk weight of the entire scale consignment/seizure and dividing it by the average dry weight of scales of a pangolin. However, the average weight of scales of a pangolin is species-dependent. Although

such parameters have not been developed for the Indian pangolin, the average dry weight of the scales of Chinese pangolin (573.47 g) has been used for scale seizure estimations (Ullmann et al. 2019).

### B. Weight-based method with a species-specific average dry weight of scales derived for an Indian pangolin

The total average number of scales present on an Indian pangolin was determined during the morpho-anatomical observation of 25 specimens. We employed indirect methods as it was not feasible to remove the scales from all the observed specimens (i.e., using destructive sampling methods on live specimens, museum specimens, and specimens in the custody of law enforcement authorities) and record the weight of individual scales. Confiscated pangolin scale consignments available at the BCNP Division of the Sri Lanka Customs were used for this purpose.

The sacks containing pangolin scales were thoroughly turned to ensure an even spread of scales to reduce the sampling bias and obtain a more representative scale sample. The varied size of pangolin scales means that smaller scales typically end up at the bottom of a sack or container when in transit (Ullmann et al. 2019). Ten scale samples of approximately 200 g in weight were drawn from the sacks containing the pangolin scales. Accordingly, the cumulative sample weighed 2.032 kg. All scales in the sample were sorted into the three morph-types (i.e., broad rhombic/scapula shaped, elongated kite-shaped, and folded scales) as described in Algewatta et al. (2021). The number of scales belonging to each morph-type was recorded. The weight of individual scales was measured using an analytical balance (RADWAG AS 310.R2) to establish the mean weight of each morph-type and the average weight of a scale of an Indian pangolin. Accordingly, the mean weight of a scale of each morph-type of an Indian pangolin was determined as follows.

$$\text{Mean weight of a scale of specific morphtype} = \frac{\text{cumulative weight of scales of the specific morph} - \text{type in the sample}}{\text{total number of scales of the specific morph} - \text{type in the sample}}$$

The average weight of scales of an Indian pangolin was derived by multiplying the average number of scales of each morph-type of an Indian pangolin by the mean weight of a scale of each morph-type. Accordingly, the derived 'average' dry weight of the scales of an Indian pangolin was used instead of the dry weight of the scales of Chinese pangolin.

### C. Scale frequency and weight-based method (Ullmann et al. 2019)

Ullmann et al. (2019) described the following procedure to estimate the number of pangolins represented in a consignment. This method allows for the number of WOE in a given seizure to be extrapolated from the total weight of the seizure. Using the following steps, it uses the weight and quantity of a sample of scales combined with the scale frequency for an 'average' pangolin.

(1) Weigh the consignment of scales

(2) Remove sampling bias by mixing the scales of one bag or container

(3) Take a nominal sample of 200 g of scales from the sampled container and count the number of scales in the sample

(4) Calculate the weight of an individual scale from the sample, given by

$$\text{The average weight of a single scale} = \frac{200\text{g}}{\text{number of scales in the sample}}$$

(5) Determine the number of scales in the entire consignment

$$\text{Number of scales in the consignment} = \frac{\text{weight of entire consignment}}{\text{Average weight of a scale}}$$

(6) Estimate the total number of pangolins represented in the consignment by

$$\text{Number of pangolins in the consignment} = \frac{\text{Number of scales in the consignment}}{\text{Average number of scales of the species}}$$

The mean number of scales on an Indian pangolin is considered to be 495.11 (Ullmann et al. 2019). This method was used to estimate the number of pangolins represented in Indian pangolin scale seizures by the Sri Lanka customs.

### D. Ullmann et al. (2019)'s method with revised average scale frequency

Ullmann et al. (2019) reported the mean number of scales on an Indian pangolin as 495.11 (i.e., 495). The average number of scales of an Indian pangolin was replaced with the figure derived from this study to update Ullmann et al. (2019) method and tested for the confiscated consignments available at Sri Lanka Customs.

### E. Scale morph-type frequency-based method to estimate the number of Indian pangolins in a seizure of scales

A new method to estimate the WOEs in a consignment was developed and tested in this study to assess its suitability to be used in law enforcement practices. The proposed method is based on the frequency of different scale morph-types of an 'average' Indian pangolin. The method is founded on the notion that the maximum number WOEs in a given consignment of Indian pangolin scales can be determined by obtaining the maximum ratio between fractions of "the number of scales of a specific morph-type in the consignment" (numerator) and the "average number of scales of the specific morph-type in a pangolin" (denominator). The suggested procedure includes;

(1) Weigh the consignment of scales

(2) Remove sampling bias by thoroughly mixing the scales of one bag or container

(3) Take a nominal sample of 200 g of scales from the sampled container and sort the scales into three morph types; elongated kite shape, folded, and broad rhombic shaped scales

(4) Count the number of scales of each morph-type in the sample

(5) The number of scales of a specific morph-type in the entire consignment is given by

$$\text{Number of scales of a specific morph} - \text{type in the consignment} = \frac{\text{number of scales of a specific morph} - \text{type in the sample}}{\text{weight of the sample}} \times \text{Weight of the consignment}$$

(6) The average number of each scale morph-type on Indian pangolin was established in 2.2. Accordingly, the number of Indian pangolins represented in the consignment can be determined by selecting the scale morph-type that gives the maximum ratio between fractions of the number of scales of the morph-type in the consignment" and the "average number of scales of the specific morph-type in a pangolin"

$$\text{Number of pangolins in the consignment} = \frac{\text{Number of scales of the specific morph} - \text{type in the consignment}}{\text{Average number of scales of the same morph} - \text{type on a pangolin}}$$

(7) Draw several samples from the consignment to increase the accuracy

## Comparison and validation of estimation methods

Confiscated pangolin scale consignments are available at the BCNP Division of the Sri Lanka Customs were used to validate new methods, and the results from different methods were compared. Complete scale counts were performed for a smaller consignment (weighing 5.8 kg). The number of pangolins represented in it was determined based on the frequency of scale morph-types (as this could be considered as the most accurate estimate). Estimates from the other sample-based methods were compared with this value.

## Statistical analysis

As the data included qualitative and quantitative information, both descriptive and inferential statistical techniques were used in data analysis. The IBM SPSS Statistics 18 (IBM Corp. 2011) was used to examine inter-species variation in the mean number and the standard deviation of scales. Also, Pearson's Correlation test was performed to find correlations between different factors/variables.

# Results

## Scale types, frequencies, and weight

In this study, a total of 25 Indian pangolin specimens were observed to determine the frequency of scales belonging to different morph-types. The average number of scales on different body regions defined in Perera et al. (2020) are reported in Table 1. Based on the 25 specimens observed in this study, an Indian pangolin on average possessed 511 scales. The dominant scale morph-types in each body region are further described in Table 1.

An Indian pangolin, on average, possessed 411 broad rhombic/ Scapular-shaped scales, 69 elongated kite-shaped scales, and 31 folded scales (Fig. 1), and the mean dry weight of each scale morph-type is reported in Table 2. The One-way ANOVA test results confirmed the statistically significant differences in mean dry weights among the three-scale morph-types ($F=6.928$, $p=0.01$). Based on the average frequency and mean dry weight of each scale morph type, the species-specific dry weight of scales for Indian pangolin was determined as 3.63 kg. Broad rhombic scales accounted for the largest proportion (85.3%) of the total dry weight of scales of an Indian pangolin, followed by elongated kite-shaped scales (9.4%) and folded scales (5.3%).

## Estimation and comparison of the size of Indian pangolin scale seizures using different methods

Estimation methods were tested for two Indian pangolin scale consignments that were seized by the Sri Lanka customs (coded as A and B). Both consignments were confiscated in 2017 at the Bandaranayake International Airport. Consignment A weighed 11 kgs and was valued at 28,275 USD while consignment B weighed 3.8 kgs with an estimated value of $ 9,768USD. However, on both occasions, no estimations have been made by the Sri Lanka Customs on the number of Indian pangolins in confiscated scale consignments.

## Estimates from weight-based methods

The commonly used weight-based method (Zhou et al. 2012; Challender et al. 2015) utilizes the average dry weight of the scales of Chinese pangolin (573.47 g) to estimate the size of pangolin scale seizures (Ullmann et al. 2019). Accordingly, the size of scale

**Table 1.** Mean number of scales present on body regions.

| Body Region | Dominant scale morph-types | Total scales (N=25) |
|---|---|---|
| Trunk | Broad rhombic> Elongated kite-shaped scale | 140.33±1.08 |
| Head and Neck | Broad rhombic> Elongated kite-shaped scale | 86.12±1.31 |
| Fore Limb Total | Broad rhombic> Elongated kite-shaped scale | 80.44±1.64 |
| Hind Limb Total | Broad rhombic> Elongated kite-shaped scale | 74.32±1.24 |
| Tail | Broad rhombic> Folded scales | 129.84±1.44 |
| Total scales | | 510.92±4.07 |

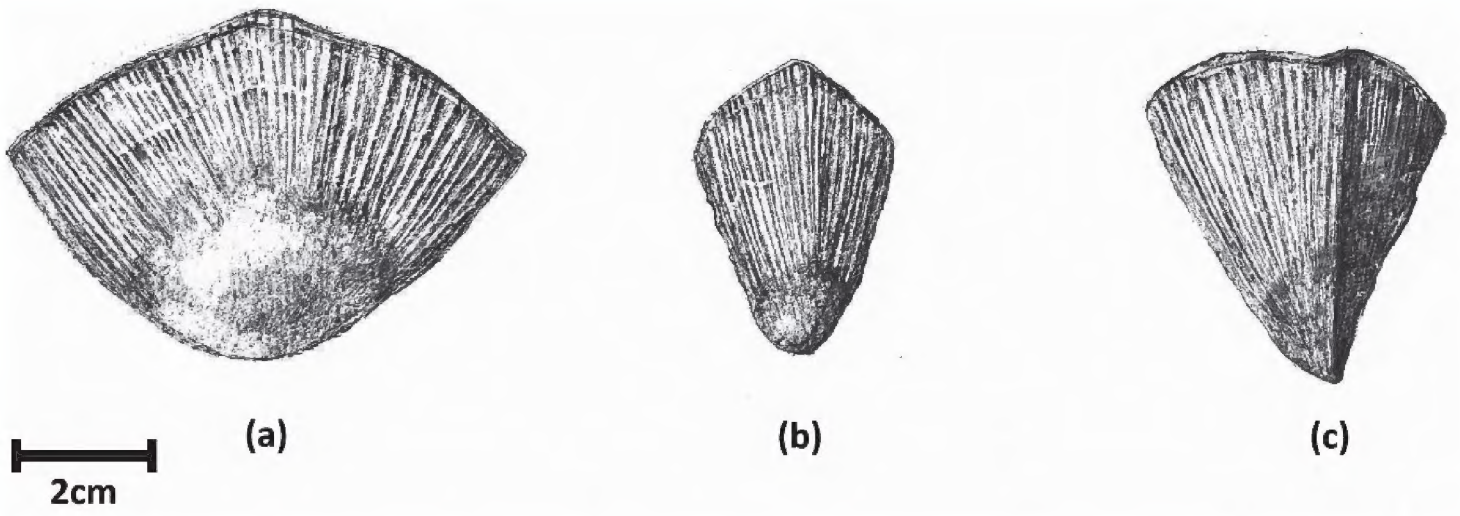


**Figure 1.** **a** Broad rhombic/scapular shaped **b** elongated kite-shaped and **c** folded scales of an Indian Pangolin.

**Table 2.** Mean frequency and dry weight of scale morph-types.

| Scale morph-type | Mean frequency | Mean dry weight of a scale | Total mean dry weight |
|---|---|---|---|
| Broad rhombic | 411.08±3.82 | 7.53±0.51 | 3095.43 |
| Elongated hite | 69.36±0.81 | 4.93±0.42 | 341.95 |
| Folded | 30.48±0.51 | 6.22±0.36 | 189.59 |
| Dry weight of scales of an 'average' Indian pangolin | | | 3626.97 |

consignments A and B were determined as 19 and 7 pangolins, respectively. Updating the weight-based method with the species-specific dry weight of scales for Indian pangolin (3.63 kgs) determined in this study (section 3.1), the size of scale consignments A and B were determined as 1 and 3 pangolins, respectively (Table 3).

## Estimates from scale frequency and weight-based methods

Ullmann et al. (2019) determined the average number of scales on an Indian pangolin as 495.11, and this figure was used in the scale frequency and weight-based method to determine the size of the scale consignments (Table 3). The estimates were made by drawing 6 and 2 random samples of 200 g from consignments A and B, respectively. The average weight of a scale was determined as 5.31 g and 5.88 g for consignment A and B, and the final estimates of the WOEs did not substantially deviate with the increase in sample size (estimates of 4.18–4.22 animals for consignment A and 1.29–1.31 animals for consignment B).

Ullmann et al. (2019)'s method was updated with the species-specific average scale frequency derived from this study, i.e., 511 scales. However, examination of confiscated pangolin scale consignments suggests that smaller broad rhombic-shaped scales on the head region of pangolins are seldom represented among tradable scales, possibly due to the difficulty of removal/extraction from the animal. Hence, we subtracted the average number of scales on the head region (64.00±5.42) from the average total number of scales of an Indian pangolin to derive a more prudent estimate of the average number of scales on an Indian pangolin in the context of trading (447 scales).

## Estimates from the scale morph-type frequency-based method

The number of scales of each morph-type contained in the samples drawn from Consignment A and B (6 samples from A and 2 samples from B) are reported in Table 3. Accordingly, folded scales had the highest ratio between fractions of "the number of scales of a specific morph-type in the consignment" (numerator) and the "average number of scales of the specific morph-type in a pangolin". Therefore, WOE estimates were based on the number of folded scales in consignments.

Table 4 summarizes the estimates for the two consignments using different methods.

## Comparison of the accuracy of estimates from different methods

To validate and compare the accuracy of estimations from different methods, a third Indian pangolin scale consignment weighing 5.8 kg was used (Consignment C). All scales in the new consignment were counted and categorized into the three morph-types. Also, each scale was measured using an analytical balance to derive the average weight of each scale morph-type (Table 5).

The average number of scales of each morph-type in an Indian pangolin is well established (Algewatta et al. 2021). The WOE in the scale consignment weighing 5.8 kg was determined based on complete scale counts of different morph-types (Table 6). The estimates on the WOEs in the consignment vary with the scale morph-type used in calculations. Theoretically, the maximum number WOEs in a given consignment of Indian pangolin scales can be determined by obtaining the maximum ratio between fractions of the number of scales of a specific morph-type in the consignment (numerator) and the average number of scales of the specific morph-type in a pangolin (denominator). For example, if there are 108 folded scales present in the consignment,

**Table 3.** Number of scales from each morph-type and estimated size of consignments.

| Scale morph-type | Consignment A | | Consignment B | |
|---|---|---|---|---|
| | No. of scales in the sample | Ratio | No. of scales in the sample | Ratio |
| Broad rhombic | 95 | 2.1 | 34 | 0.8 |
| Elongated kite | 60 | 7.9 | 18 | 2.5 |
| Folded | 42 | 12.4 | 10 | 3.0 |

**Table 4.** Estimated size of the Indian pangolin scale seizures from different methods.

| Estimation Method | Estimated size of the scale seizure (WOEs) | |
|---|---|---|
| | Consignment A | Consignment B |
| A. weight based method (Challender et al. 2015; Challender and Waterman 2017; Zhou et al. 2012) | 19.2 (20) | 6.6 (7) |
| B. Weight-based method with species-specific average dry weight of scales derived for an Indian pangolin | 3.0 (3) | 1.1 (2) |
| C. Scale frequencies and weight-based method (Ullmann et al. 2019) | 4.2 (5) | 1.3 (2) |
| D. Ullmann et al. (2019)'s method with revised average scale frequency | 4.6 (5) | 1.5 (2) |
| E. Scale morph-type frequency-based method using folded scales | 12.4 (13) | 3.0 (3) |

† Conservative estimate indicated within parenthesis.

**Table 5.** Frequency and weight of each morph-types of the scales in the validation consignment.

| Morph type of the scale | Frequency | Mean weight (g) | Total weight (g) |
|---|---|---|---|
| Broad rhombic-shaped | 703 | 5.88±3.82 | 4135.48 |
| Folded | 108 | 6.48±3.82 | 699.60 |
| Elongated kite-shaped | 199 | 4.81±3.82 | 958.34 |
| Total | 1010 | | 5800.27 |

**Table 6.** Estimated WOEs in the validation sample.

| Method | Estimated WOEs |
|---|---|
| Scale morph-type frequency-based method using folded scales | 3.5 (4) |
| Scale morph-type frequency-based method using elongated-kite shaped scales | 2.9 (3) |
| Scale morph-type frequency-based method using broad rhombic scales | 2.0 (2) |
| Weight-based method (Challender et al. 2015; Challender and Waterman 2017; Zhou et al. 2012) | 10.1 (11) |
| Weight-based method with a species-specific average dry weight of scales derived for an Indian pangolin | 1.6 (2) |
| Scale frequencies and weight-based method (Ullmann et al. 2019) | 2.0 (2) |
| Ullmann et al. (2019)'s method with revised average scale frequency | 2.3 (2) |

† Conservative estimate indicated within parenthesis.

and since the average number of folded scales in an Indian pangolin is 31, a minimum of four animals must be killed to extract 108 folded shape scales (108/31=3.5). For the given consignment, this is the most accurate estimate of the number of WOEs; hence, the estimates from other methods were compared to the WOE estimate from folded scales to validate their accuracy. The same calculation was performed using elongated kite scales (199/69=2.9 WOE) and broad rhombic scales (703/347=2 WOE) present in the consignment, which yielded a comparatively lesser number of WOEs to the WOE estimate from folded scales (Table 6).

## Discussion

The demand for Indian pangolins in the IWT is rising with exploitation pressure on Indian pangolin populations in new source markets such as Sri Lanka and Nepal (Challender and Waterman 2017; Mahmood et al. 2019). Indian pangolins show a wide distribution throughout Sri Lanka, occurring in a variety of habitats up to 1850 m above mean sea level with higher concentrations in the North-west, North-central, South-west lowlands, and South-eastern parts of the island (Karawita et al. 2018; Karawita et al. 2020). However, they have recently faced the threat of hunting and poaching for scales (Karawita et al. 2016; Perera and Karawita 2020). The absence of an accurate conversion parameter to determine the WOEs in confiscated scale consignments is an issue faced by law enforcement authorities. The current conversion parameters in use can lead to possible over-estimations or under-estimations WOEs in trade.

Following the descriptions and established protocols in literature (Perera et al. 2020; Algewatta et al. 2021), the species-specific dry weight of scales of an Indian pangolin was determined as 3.63 kg, based on the average frequency and mean dry weight of each

scale morph type. Although this species-specific conversion parameter was indirectly approximated based on scale frequency counts of 25 specimens, and an average weight of each scale morph-type determined by weighing individual scales from scale seizures, we argue that it is the most accurate conversion parameter for the species published up to now. Nonetheless, scale frequency counts and an average weight of a scale of an Indian pangolin determined using destructive methods (remove each scale from the body of a pangolin and measure the weight) would yield the most accurate conversion parameter.

Our observations on confiscated scale consignments in Sri Lanka suggest that Indian pangolin scales in the IWT mainly comprise scales extracted from adult and sub-adult pangolins. Therefore, the scales used for dry weight measurements were predominantly from adults and sub-adults. Juvenile Indian pangolins have soft and smaller scales on their bodies, and the scales harden as they grow (Mahmood et al. 2020). Also, scales of juveniles are less differentiated into the three scale morph-types compared to sub-adults and adults. Hence, the consignments which were used to measure individual weights of scales did not include scales of juvenile pangolins.

The weight-based method utilizes the average dry scale weight of Chinese pangolin (573.47 g), as the species' conversion parameters have been well established (Zhou et al. 2012; Ullmann et al. 2019). However, the Chinese pangolin is comparatively small, typically weighing between 3 to 8 kg, and could measure up to 89 cm (Wu et al. 2020). On the other hand, recent studies on morphometrics of Indian pangolins suggest that an Indian pangolin can outgrow the African Giant Pangolin (*Smutsia gigantea*), and an adult male Indian pangolin can weigh over 35 kg and measure up to 178 cm in length (Algewatta et al. 2021; Perera et al. 2021). Using the dry weight of the scales of a Chinese pangolin to determine the WOEs of Indian pangolin scale consignments could lead to severe overestimations. This was evident by the results of this study, where the highest number of WOEs were estimated with the weight-based method (Tables 4 and 6). Replacing the dry weight of the scales of a Chinese pangolin with the species-specific dry weight of scales derived for an 'average' Indian pangolin yielded more realistic estimates of WOEs.

The WOE estimation method based on scale frequency and weight proposed by Ullmann et al. (2019) assumes that an Indian pangolin has 495 scales on average. Based on a larger sample of Indian pangolin specimens (n=25), we determined that an Indian pangolin has 447 'tradable' scales as smaller scales on the head region are difficult to remove, thus seldom found in scale seizures. We argue that this is a more prudent estimate of the scale frequency of pangolin in IWT. Nonetheless, the final estimates of the WOEs in seizures derived from Ullmann et al. (2019) method and, when scale frequency is replaced by this study's estimate (447 scales), did not differ substantially.

This study further proposed and tested a method based on the frequency of scale morph-type to estimate the WOEs in Indian pangolin seizures. We argue that the maximum number WOEs in a given consignment of Indian pangolin scales can be most accurately determined by obtaining the maximum ratio between fractions of "number of scales of a specific morph-type in the seizure" (numerator) and the "average number of scales if the same morph-type in a pangolin" (denominator). Folded scales are the least frequent scale morph-type (31 scales) in an Indian pangolin (Algewatta et al. 2021); thus, for the seizure of Indian pangolin scales examined in this study, this

is the most accurate estimate of the number of WOEs. Using other scale types in the calculations leads to underestimates, as evident by the results (Table 6). Similarly, all other estimation methods tested in this study yielded underestimations of the WOEs.

Both Ullmann et al. (2019)'s method and the proposed scale morph-type frequency-based method are based on samples drawn from the seizure. The sample size has a significant effect on the accuracy of WOE estimates. For instance, our observations revealed that about 4 to 5 samples of 200 g had to be drawn from a scale consignment weighing 5.8 kg to arrive at consistent estimates of WOEs from these two methods (i.e., cumulative sample of about 15% of the weight of the consignment was required). Furthermore, smaller scales in containers are likely to settle at the bottom; hence thorough mixing is required before drawing samples (Ullmann et al. 2019). Thus, using Ullmann's et al. (2019) method and the proposed scale morph-type frequency-based method for large seizures of Indian pangolin scales may be cumbersome procedures for law enforcement entities to follow, especially in occasions where quick estimation of WOEs is desired. However, the proposed scale morph-type frequency-based method can yield more accurate estimates of WOEs for smaller consignments often confiscated at airports by customs officers.

The weight-based method with a species-specific average dry weight of scales derived for an Indian pangolin can be recommended as a more practical approach in estimating WOEs. This simple and straightforward approach only requires the weight of the seizure. In the Sri Lankan context, there have been about five confiscations of Indian pangolin scales by the law enforcement authorities between 2012 and 2019, where WOEs have been estimated on only one occasion (Perera et al. 2017; Perera and Karawita 2020). The four seizures made by the Sri Lanka Customs at Bandaranayake International Airport weighed between 1.7 and 11 kgs, and the WOEs have not been estimated in determining the fines (Perera and Karawita 2020). The largest stock of 130 kgs of Indian pangolin scales was discovered from Kalpitiya in the North-western part of the country by the Police in November 2017. It was estimated that the seizure represents approximately 150 WOEs with no conversion parameters cited (Perera and Karawita 2020). On weight-based conversions, it appears that 0.87 kg has been used as the conversion factor. According to our study findings, these are serious overestimations of the WOEs, where the seizure would represent only 37 WOEs according to species-specific dry weight of scales established in this study. As such, the findings of this study will be beneficial in the future for the reliable estimation of WOEs in Indian pangolin scale seizures. The scale morph-type frequency-based method proposed in this study can be further developed as a validation tool.

## Conclusion

An Indian pangolin, on average, has 411 broad rhombic scales, 69 elongated kite-shape scales, and 31 folded shape scales. The mean dry weight of the three-scale morph-types is 7.5 g, 4.9 g, and 6.2 g, respectively. Accordingly, the average dry weight of scales of an Indian pangolin in IWT is 3.6 kg. Using the species-specific dry weight of scales for Indian pangolin (3.6 kgs) as the conversion parameter in weight-based conversions

yields more realistic estimates of WOEs involved in IWT, and the method is particularly suited for large seizures of scales. The proposed scale morph-type frequency-based method provides the most accurate estimates of the WOEs but has limitations in the applicability at ground level. Nonetheless, the method can be used to determine the WOEs for smaller seizures typically confiscated at airports.

## Acknowledgements

The authors would like to acknowledge the Department of Wildlife Conservation, Sri Lanka, Pinnawala Zoological Garden of the Department of National Zoological Gardens, National Museum Colombo Sri Lanka and Sri Lanka Customs for granting permission to access their specimens, and the University of Sri Jayewardenepura, Sri Lanka for facilitating the research.

This research was funded by the University of Sri Jayewardenepura (Research grant No: ASP/01/RE/SCI/2017/14) and the Center for Sustainability of the Department of Forestry and Environmental Science, University of Sri Jayewardenepura.

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